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Art. IX.—*On a Limburgite Rock occurring as a Volcanic Plug at Balwyn, near Doncaster.*

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and

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(With Plates XL. and XLI.)

[Read 8th June, 1911.]

General Description of the Locality and Occurrence.

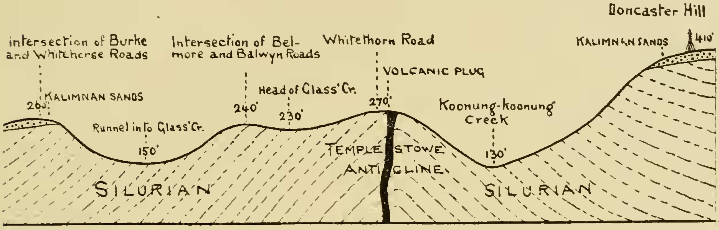
The bedrock of this district is formed of more or less folded mudstones and sandy shales, belonging to the silurian (melbournian) series. The highest points in the neighbourhood are at Doncaster, Yarrabat Avenue, and Balwyn township, on the 410, 380 and 320 contour lines respectively. In common with other intermediate localities, these eminences are capped with red tertiary sands of kalimnan age (lower pliocene): remnants of the vast sheet of sand-rock which at one time formed a cover to the great Yarra or Nillumbik peneplain[1] of this part of Victoria, before it was dissected by the present river system.

The Balwyn occurrence of the basic lava herein described, and later shown to be a basic dolerite related to the limburgites, is situated in a paddock of the Whitethorn Estate (now chiefly comprised in an allotment belonging to Mr. J. R. Lewis[2]), at about 800 feet down the Whitethorn Road, north from the Belmore Road, and about 200 feet east from the road. The exposure presents the appearance of a low, but distinct mound of oval or lenticular outline, rising very slightly above the contour of the silurian rock of the immediate vicinity, and sloping

1 For description of this peneplain see J. T. Jutson, Proc. Roy. Soc. Victoria, vol. xxiii, n.s., pt. 2, 1911, p. 447.

2 For facilities given for access to the ground our best thanks are tendered to this gentleman.

down on the south-eastern side to lower ground bounded by a small creek. The mound has been rendered more conspicuous by the accumulation of excavated rubble which has been thrown out around the area worked for the stone. No actual junction with the country rock (silurian mudstone) was found, even after prolonged search ; but close at hand, near the small creek before mentioned, the mudstone is indurated in a peculiar manner, and a small monadnock stands out as the result of unequal hardness and encircling denudation.



GEOLOGICAL SECTION FROM BURKE ROAD TO DONCASTER TOWER.
LENGTH OF SECTION 4 MILES. VERTICAL SCALE EXAGGERATED 13.2 TIMES.

The height of the outcrop of the lava above sea-level is 270 feet. The exposure, which is situated on the sloping sides of the Koonung-koonung Creek basin, appears to have been discovered many years ago, and was locally used for supplying a hard stone, of which, by the way, there is a decided lack in this locality. Some of the lava was formerly employed for metalling the Doncaster Road, but was eventually given up on account of the objection of the stonebreakers to use material harder than the Collingwood bluestone, to which, together with the local indurated sandstone, they have now adverted. The conspicuous part of the mound formed by the lava and the excavated rubble is about 230 feet in length and about 100 feet broad. Altogether with the exposure of lava and volcanic soil on the south-eastern slope, this area would be increased more than four times.

The mode of occurrence of the rock at once conveys the idea that it is a volcanic plug or neck, which has broken into and through the silurian mudstone and sandstone of this district. That it is a pipe or terminal flow is fairly evident from the shape of the exposure. The rock has probably solidified at or near the surface, as there are no particularly large crystals in the magma, the phenocrysts being of very moderate size. The rock is decomposed in the superficial layer, but in the interior is dense and of a blue-black colour. There are a few vesicles in the mass, but many of the cavernous parts of the surface-material are seen to be due to the decomposition of the olivines. It was found impossible to discover a clean, exposed section of the lava, but at one spot we were able to see the jointed, rubbly rock lying on decomposed lava to some depth. Numerous joint-planes have completely broken up the rock, and the form of the fragments is platy rather than cuboidal or prismatic, as in ordinary basalt. Some of the less dense pieces, in contrast to the dark, rusty brown colour of the majority of the lava-slabs, are of an earthy yellow to sage-green colour; a difference due to the presence of a larger quantity of decomposed olivine.

Detailed Description of the Balwyn Lava.

Megascopic Characters.—Typical rock specimens are dense, and dark blue to black in the decomposed parts. The weathered surface is yellowish to dark brown, and forms a thin crust on the exposed portion. Very frequently the surface shows a pitted structure which is very conspicuous, and due to the removal of olivine phenocrysts. Fractured surfaces reveal a few glassy phenocrysts of olivine. Some of the rock fragments picked up at the excavations are rich in alteration products of the ferro-magnesian minerals, and of a dull green colour.

Microscopic Characters of the Black Lava.—Ground-mass with hyalopilitic structure; also indications of local fluxion structure, with numerous phenocrysts of olivine, large and small, and an occasional pale green augite (= diopside). The ground-mass consists of closely textured crystals of minute augites, a moderate proportion of felspar laths,[1] numerous small crystals of magnetite, and some larger platy ilmenites, together

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1 In a slide of the rock analysed for the present paper, the felspars are more numerous; nevertheless the strong basic character of that particular specimen is shown by its high specific gravity (2.994).

with a little interstitial brown glass. (See Plate XL., Fig. 1). Felspar microliths consisting of labradorite of the medium type, having an extinction angle of – 35 deg. Augite, chiefly occurring in the ground-mass. The crystals are of long prismatic habit, and of a deep hazel-brown colour. In the less dense samples this mineral occurs ophitically intergrown with the felspars. Average dimensions, .11 mm. × .023 mm.

Diopside, rare; a few phenocrysts present, of a pale green colour, and with feeble pleochroism. Several twinned crystals occur in one of the slides, which Mr. D. J. Mahony, M.Sc., was good enough to examine with us, and he confirms our determination of this mineral. The presence of diopside may account for the small percentage of Cr_2O_3 recorded in the analysis appended to this paper. Olivine, occurring, 1st—as phenocrysts, short, stout prismatic, or of tabular habit, the largest having a length of about 2 mm.; 2nd—as rounded granules, their shape being probably due to partial resorption by the magma. The olivines are colourless to pale green, somewhat corroded and often partially altered on the margins and along cleavage planes to a dull olive green or yellow substance. Several large phenocrysts of olivine exhibit a poicolitic structure, being filled with minute included crystals of ilmenite or possibly (?) picotite. (See Plate XLI., Fig. 4). The olivine also occasionally contains strings of brown glass inclusions.

Magnetite.—Abundant as small crystals disseminated through the magma, and rectangular or triangular in section; sometimes occurring in linear series. This mineral shows a tendency to form irregular zones around the olivine phenocrysts, and especially the rounded granular crystals. (See Plate XLI., Fig. 3). The magnetite is probably more or less titaniferous, as it shows some translucency, being of a brown colour in very thin sections by transmitted light.

Ilmenite.—Some medium-sized tabular crystals, showing skeleton structure around the margins, having a sub-metallic lustre by incident light. (See Plate XL., Fig. 2). Numerous minute truncated triangular crystals in this ground-mass are also probably referable to the same mineral.

Zeolites.—Analcite appears to be present as a transparent isotropic mineral filling minute, irregular cavities, and often penetrated by acicular crystals of natrolite.

Microscopic Characters of the Dark-green Lava.—The general structure of this rock is much the same as the darker, normal variety, but it has undergone much secondary change. The olivines are largely serpentinised, and the more ferriferous are changed into a substance like iddingsite, which shows marked pleochroism and prismatic cleavage cracks. Magnetite is very abundant in this rock.

The above rock is a fairly typical limburgite,[1] olivine and augite both being present, the latter forming a large proportion of the ground-mass, whilst the felspar is comparatively rare. By its mode of occurrence this rock, as Prof. Skeats has kindly pointed out, seems to be related to the monchiquites, but it is not typical, seeing that neither biotite nor hornblende occur in it. (See footnote at end of paper).

The specific gravity of this rock at 4 deg. C. is 2.994, as determined by Mr. P. W. G. Bayley, Assoc. S.A.S.M., of the Victorian Mines Department Laboratory. We are also indebted to that Department for the analysis of the Balwyn rock, prepared by Mr. Bayley. For comparative purposes the analyses of the Woodend and Bendigo examples are also appended (see last page).

Notes on some Previously Recorded Occurrences of Volcanic Plugs of a Basic Character.

Volcanic plugs and necks have been recorded from several widely separated localities in Victoria, as, for example, near Coleraine, near Castlemaine, at Anderson's Inlet, and at Woodend.

The two conical hills near Coleraine, known as Adam and Eve, which were noted by the late Mr. Dennant,[2] are in all probability

1 The best known British example of limburgite is perhaps that from Whitelaw Hill, near Haddington, described by Dr. F. Hatch (Trans. Roy. Soc. Edin., vol. xxxvii., 1892, pp. 116, 117, pl. I., fig. 1). It closely resembles the Balwyn rock in its mineralogical and chemical composition, the silica being in the proportion of 40 per cent., and the magnesia 12 per cent. Its specific gravity is 3.03. A specimen from the type locality of Limburg, described by Rosenbusch, gave a specific gravity of 2.829 (See Cole, G. A. J.—"Aids in Practical Geology," 1891, p. 241).

2 Rep. Aust. Assoc. Adv. Sci., 1893, Adelaide, p. 395. Mr. E. G. Hogg refers to the same rock as an olivine basalt (Proc. Roy. Soc. Victoria, vol xii., n.s., 1899, p. 91).

volcanic plugs. Mr. Dennant states that "The rock is black and so dense that I have not been able to make any section really transparent." He also mentions the specific gravity of the rock as reaching 3. By the courtesy of Mr. R. H. Walcott, F.G.S., we have been able to examine a section of the above rock which was made by Mr. Dennant, and comprised in his collection, now at the National Museum. The slide is labelled as from Mount Adam. It closely resembles the Balwyn rock in its great density and general composition; but, nevertheless, appears rather to belong to the more basic type of the olivine basalts, since the basic oxides are not so abundant, nor the olivines so ferriferous. The Mount Adam rock may be briefly described as follows:—Ground-mass fine-grained, taxopilitic; composed of finely felted crystals of plagioclase felspars, together with minute tabular and prismatic augites and small crystals of olivine of the second generation, and fairly abundant but minute magnetite crystals. A moderate number of phenocrysts of olivine are scattered through the rock, averaging about .75 mm. in length, and with pale brown decomposition areas along the fracture planes. Also an occasional phenocryst of augite of a pale brown or wine colour.

The rock forming a volcanic neck at Mount Consultation, near Castlemaine, is described by Dr. T. S. Hall[1] as a "basalt, almost black, very fine-grained, rarely vesicular," and having "in some places a platy structure." This rock corresponds in all the above particulars with ours, the platy structure in the Balwyn rock being a very marked feature.

In South Gippsland, near Anderson's Inlet, there are numerous volcanic necks which have been described by Mr. A. E. Kitson.[2] Many of these are fragmental volcanic rocks, from which one may infer that explosive action played an important part during their extrusion. Several of the rocks mentioned in detail by Mr. Kitson resemble magma basalts, but since the actual mineralogical composition is not given, it is impossible to say whether they belong to the augites or the limburgites; the remainder are referred to olivine dolerite and basalt. The

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1 Proc. Roy. Soc. Victoria, vol vii., n.s. (1895), p. 81.

2 Ibid, vol xvi, n.s., pt. 1. (1903), p. 154.

dense, hard, blue basalt of volcanic neck No. 3[1] may possibly be allied to ours. Those rocks falling into type *c* of Kitson most nearly approach that from Balwyn. They are described as "A dense or fully crystalline basalt as a rule, with or without amygdules of calcite and small patches of olivine. This occurs as small plugs and dykes."[2] These rocks are regarded by Mr. Kitson as post-jurassic in age, and almost certainly contemporaneous with the older basalt of Flinders and the Mornington Peninsula.

An interesting occurrence of some small plugs of dense black prismatic basalt, from south of Woodend, Macedon district, has been lately described by Professor Skeats,[3] who refers them to the limburgites. In section this rock "shows phenocrysts of fresh olivines, set in a dark, dense, fine-grained ground-mass, consisting of lath-shaped minute augites, magnetite and small felspars with a residuum of dark glass." The age of this rock Professor Skeats provisionally regards as middle cainozoic (?). In noting the structural likeness of the Woodend limburgite to that from Balwyn, it strikes one as very probable that similar volcanic effusions may yet be found traversing the older rocks in the area between the last-named locality and the district of Central Victoria, especially since the Balwyn occurrence seems to be a plug which has been uncovered by denudation from the action of the present river system;[4] and thereby indicating the possible proximity of other effusions which have not quite reached the upper limiting surface of the basal rocks, or have shrunk down again within the pipes they may have formed.

Turning to New South Wales, in the neighbourhood of Sydney, notably near Parramatta, there are numerous plugs of basic lavas ranging through the limburgites, magma basalts and augitites. These rocks are often indicated on the surface as a series of isolated lenses, and they frequently end abruptly at a few feet from the present land surface; whilst the shales through which they rise appear shattered.[5] The Sydney basic

1 Ibid, loc. cit., p. 156.

2 Loc. cit., p. 156.

3 Pres. Address, Sect. C, Austr. Assoc. Adv. Sci. (1909), p. 206.

4 It is within the recollection of one of us (A.O.T.) that the early excavations were made in two or more places, and those undertaking it were guided by the stones lying on the surface.

5 M. Morrison—"Notes on some of the Dykes and Volcanic Necks of the Sydney District, etc." Records Geol. Surv., N. S. Wales, vol. vii., pt. iv. (1904), p. 262.

lavas are held to be of any age later than triassic. The limburgite of the Macedon district is regarded by Professor Skeats as of the last phase of effusion before the flow of the newer basalt.

The rock described by Mr. G. W. Card[1] from The Peak, Upper Burragorang, bears a marked resemblance to the Balwyn rock both in hand specimens and under the microscope, but differs essentially in having a fair amount of nepheline disseminated through the magma. A point in common between the two rocks is the occurrence of inclusions of an exogenic character, consisting of pyroxene and picotite in mutual association.

One other rock occurrence of the limburgite type from Victoria may here be mentioned, which is found in the form of dykes cutting through the older rocks, and not as volcanic plugs or necks. This is the series of basic dykes described by Mr. (afterwards Dr.) A. W. Howitt as traversing the sedimentary rocks in which the saddle reefs of Bendigo have been found.[2] According to Dr. Howitt these rocks have been injected into fissures after the formation of the quartz reefs. This particular rock is referred by Howitt to the limburgites; and he remarks that "The extraordinary freshness of some samples of this rock from Bendigo suggests that it is of comparatively late geological age." It may, therefore, belong to the same series of effusions as the Woodend and Balwyn types. The mineralogical composition of the above rock generally resembles both of the other types just mentioned, as the following notes from Dr. Howitt's description show, although it differs from both those types in having numerous crystals of amphibole in the ground-mass, whilst the felspars are entirely absent: magma of very basic character; ground-mass with pale brown to colourless glass. Microliths and skeleton crystals of amphibolite, often arranged in a stellate manner around the magnetite crystals. Felspar absent. The augite crystals follow the generation of microliths. Porphyritic crystals of augite and olivine; the latter colourless, ranging from fresh to completely altered.

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1 Card, G. W.—"On the occurrence of Nepheline in Post-triassic Basalts of the Hawkesbury Sandstone Area." Ibid, vol. vii., pt. iii. (1903), p. 236.

2 Howitt, A. W.—"Notes on Samples of Rocks collected in the 180 Mine at Bendigo.' Special Rep. Dept. Mines, Victoria, 1893, pp. 3, 4. Mr. R. H. Walcott, F.G.S., of the National Museum has kindly directed our attention to the above paper.

In the sequel to this paper the analyses of the Bendigo and the Woodend rocks are quoted, where it will be seen that the former is richer in lime, but otherwise they agree pretty closely, especially in the percentages of the basic elements.

Suggestions and Conclusions as to the Age and Relationships of the Volcanic Pipe at Balwyn.

The presence of basic lava in this locality leads us to look around for similar ocurrences, but without avail. Basalt occurs, it is true, to the N.W. of Heidelberg, and to the W. of Balwyn at Collingwood ; but in these instances the lava is found as more or less continuous sheets filling up former river courses. They are, moreover, easily recognisable as typical lava flows of the younger, or newer volcanic, series.

The decomposed state of the lava and its comparative isolation, as well as its almost identical chemical and physical composition, as compared with well-recognised lavas of the older series of basalt flows, compels us to place this occurrence in the same category. It is here apposite to remark that Professor Skeats has referred his recorded limburgite occurrence at Woodend to the same series of the older basalts, for he gives the sequence of the alkali series of "(?) middle cainozoic" age as ranging from solvsbergite, etc. . . . to limburgite and newer basalt.[1]

As regards the age of the greater part of the flows and vents of the older basalt, the argument for their being miocene (i.e., janjukian) is strongly supported by their intercalation between beds of janjukian age on the Victorian coast,[2] and along the Moorabool Valley. The position and local occurrence of the Balwyn limburgite plug points to the probable conclusions that, assuming it was formed in miocene times (i.e., janjukian), it either cooled considerably below the original surface of the silurian bedrock, and was afterwards exposed when the Koonung-koonung Creek basin was carved out by kalimnan or post-

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1 President's Address, Section C, Austr. Ass. Adv. Sci., Brisbane, 1909, p. 203.

2 See Note on the Geology of the country about Anglesea. T. S. Hall, Proc. Roy. Soc. Victoria, vol. xxiv., n.s., pt. 1 (1899), p. 49 et seq.

kalimnan fluviatile denudation; or that it had already reached the original surface of the peneplain as a vent, and was subsequently planed down along with the bedrock. The former hypothesis is the more tenable, as the lava, being so tenacious, would, if extruded to the surface, have tended to weather out and stand considerably above the comparatively soft bedrock, and thus indicated its differential structure by the formation of a monadnock.

That this occurrence of lava in so isolated a spot may be directly connected with crustal folding prior to the formation of the Yarra or Nillumbik peneplain, is suggested by the fact that it occurs on the Templestowe anticline of Jutson[1] (see text figure), and directed, in its major axis, with the same line of strike as that of the quartz reefs containing antimony and gold at Templestowe. The nearest occurrences of the older basalt on either side of Balwyn are at Lilydale on the east, where there is a vent represented by tuff and cinder cones; and Flemington, on the west, represented by a rather massive flow of spheroidal basalt.[2] The Lilydale volcanic series is situated close to the fault boundary of the Croydon senkungsfeld, which may be directly connected with that remarkable series of tuffs and lavas.

ANALYSES OF WOODEND, BENDIGO AND BALWYN ROCKS.

	Woodend	Bendigo	Balwyn
SiO_2	43.58	39.32	45.56
Al_2O_3	11.46	17.53	13.32
Fe_2O_3	3.40	3.07	2.30
FeO	9.13	9.12	9.68
MgO	10.80	8.00	11.12
CaO	0.88	10.38	8.77
Na_2O	2.18	2.44	3.02
K_2O	2.13	2.04	1.53
H_2O+	2.40	5.10	1.28

1. Proc. Roy. Soc. Victoria, vol. xxiii., n.s., pt. 2, (1911), p. 522.

2 Note—In the discussion following the reading of the present paper, Prof. Skeats remarked on the interesting discovery of a similar monchiquite rock occurring as a dyke in the closely associated Warrandyte anticline. (See Jutson, Proc. Roy. Soc. Victoria, vol. xxiii., pt. ii., 1911, p. 528).

	Woodend.	Bendigo.	Balwyn.
H_2O – (110°C.)	0.47	2.20	0.27
CO_2	nil		nil
TiO_2	3.32	—	3.00
P_2O_5	0.95		0.71
SO_3			nil
Cl_2	trace		0.05
Cr_2O_3			0.06
MnO	—	—	0.19
NiO			0.01
CoO			trace
Li_2O			nil
	90.70	99.20	100.87
		less O	0.01
			100.86

EXPLANATION OF PLATES.

Plate XL.

Fig. 1.—Section of limburgite-rock (monchiquite), showing general structure. × 18.

Fig. 2.—Crystal of ilmenite surrounded by olivine, felspar and augite. × 140.

Plate XLI.

Fig. 3.—Crystals of olivine, with zones of magnetite (probably titaniferous). × 140.

Fig. 4.—Intergrowth of olivine and magnetite, showing a rude centric structure (poicolitic). × 140.